2014

A novel myoelectric training device for upper limb prostheses

Ryan Clingman
Virginia Commonwealth University, clingmanr@vcu.edu

Peter Pidcoe
Virginia Commonwealth University, pepidcoe@vcu.edu

A Novel Myoelectric Training Device For Upper Limb Prostheses

Ryan Clingman, *Member, IEEE*, Peter Pidcoe, *Member, IEEE*

***Abstract*—A training system intended for myoelectric prosthetic hands for upper limb amputees was developed to assist in learning myoelectric control schemes and training muscle isolation. The trainer allowed a user to operate a remote controlled car by use of a control scheme commonly used in myoelectric prosthetic hands. The trainer was designed to be easy for therapists to use and more engaging for the user than current methods of signal training.**

Preliminary testing of the trainer was conducted with eight non-amputee adult volunteers. The results indicated that the trainer could be a useful tool for myoelectric training in upper limb amputees. All subjects' skill with the myoelectric control scheme improved over the course of testing, with the improvements being greater at the beginning of the training period than at the end. Whereas the individual subjects' performance varied greatly at the beginning of the training, the subjects had achieved a more uniform level of performance by the end of the training, approaching the minimum possible values for the assessments.

***Index Terms*—Electromyography, man machine systems, myoelectric control, prosthetics, rehabilitation.**

I. INTRODUCTION

An important factor in a patient's acceptance of a prosthetic limb is the training they receive on how to use it. The methods currently employed to train prostheses users, however, have not matured as quickly as the prostheses themselves [1]. The ability to produce appropriate myoelectric signals to control electronic prosthetics is necessary to use them, making appropriate training of the user before receiving the device important in its success [2]. Proper training in the use of a myoelectric prosthesis is cited as one of the most important factors in a patient accepting and using the prosthesis [3] [4] [5], and proper training has been shown to double the acceptance rate of myoelectric prostheses [6]. To this end, training systems using features such as interactive video games to help maintain the patient's motivation are sometimes used [7].

Training for myoelectric prosthetics is typically broken down into three phases: signal training, control training, and functional training. (A) Signal training involves displaying live electromyograph (EMG) signals from the user's measurement sites, allowing the user to learn how to activate and isolate individual muscles, and to associate them with the desired movements. (B) Control training involves learning to use the muscles appropriately through the use of a more active system of feedback such as computer simulations, games, or toys controlled by the patient's EMG outputs, allowing for further training to isolate the muscles to accomplish more concrete tasks. (C) Functional training involves training the user to use the actual prosthesis for activities of daily living, starting with basic motor skills and working up to more advanced tasks. All of this training together helps the patient to become more accustomed to wearing the prosthesis and more skilled in using it on a regular basis [8] [9].

The signal training and control training steps used with modern prosthetics typically involve either a simple form of visual feedback, using a computer to show signal amplitudes, or a series of repetitive movements that the patient must produce in order to aid learning. The researchers thought that a more free-form version of training could be used to achieve levels of learning comparable to existing methods, while better maintaining the patient's attention and motivation. This study was designed to determine the effectiveness of this type of myoelectric training by providing subjects with a toy car controlled through an EMG system and measuring their ability to drive the car accurately.

II. METHODS

Eight healthy adult subjects (4 male and 4 female) were asked to navigate a remote control car through a 40 ft. slalom course using myoelectric control of both the steering and propulsion elements. The experiment used a randomized cross over design. Participants trained in six sessions lasting less than one hour each, with the first five consecutive sessions for a subject being spaced one week apart and the final session 90 days after the fifth session. Subjects had an average age of 27.1 years (SD = 4.83) and had no known orthopedic or neurological issues.

The control system used a well-established myoelectric control scheme, known as a two-site three-state control scheme, where EMG signals from one muscle control one action, EMG signals from a second (typically antagonistic) muscle control the opposite action, and rest is considered a third state [10]. Because the car had more than three states, control of the car with this control scheme required the use of both upper extremities. The subject's dominant arm was used to control the steering direction while the non-dominant arm

Manuscript received March 27, 2013; revised November 11, 2013; accepted March 30, 2014.

R. Clingman is with the Department of Biomedical Engineering, Virginia Commonwealth University, Richmond, VA 23220 USA (e-mail: clingmanr@vcu.edu)

P. Pidcoe is with the Department of Physical Therapy, Virginia Commonwealth University, Richmond, VA 23219 USA (e-mail: pepidcoe@vcu.edu)

was used to control forward and reverse propulsion, making this a dual two-site three-state system. Because limb loss can happen at various levels, it is important that a training device should function adequately using a variety of muscle groups commonly used in myoelectric prosthetic devices for different levels of amputation. The most common muscles used for myoelectric control for transradial, transhumoral, and shoulder disarticulation amputations were used in this experiment. Steering control was varied by using these proximal, medial, and distal muscle groups in separate sets of trials. Subjects were randomly assigned to one of two groups. Half of subjects progressed through the muscle groups in a distal-to-proximal order for sequential sets of trials, while the other half were assigned to progress through the muscle groups in a proximal-to-distal order.

To control the steering of the car, pairs of 34 mm clinical surface electrodes were placed directly next to each other, providing spacing of the electrodes similar to the placement used in modern myoelectric prosthetics. The electrodes were placed over three opposing pairs of muscles in the dominant arms of subjects according to standard clinical placement guidelines [11] [12]. Steering control electrodes were placed in a distal group over the flexor carpi radialis muscle and extensor carpi radialis muscle of the wrist, a medial group over the biceps brachii muscle and lateral head of the triceps brachii muscle of the elbow, and a proximal group over the pectoralis major muscle and posterior deltoid muscle of the shoulder. To control the propulsion of the car, additional electrodes were placed over the same wrist flexors and extensors in the contralateral arm of subjects. These electrode sites were chosen because they are routinely used for the control of myoelectric prosthetic arms due to their relative ease of volitional control of the EMG signal [10] [13] [14] [15]. For each pair of antagonistic muscles in use for the steering arm, the flexor/internal rotator muscle was used to control the left turning of the car while the extensor/external rotator muscle was used to control the right turning of the car. For the propulsion arm, the wrist flexor was used to control forward propulsion and the wrist extensor was used to control reverse propulsion. A rough illustration of the placement locations and associated functions of the electrodes can be seen in Fig. 1.

Contemporary myoplastic amputation techniques involve fixing the ends of the muscle groups which are cut in the amputation to the ends of antagonistic muscle groups, covering the end of the amputated bone(s). This is done to prevent a number of complications in the resulting stump due to leaving the muscle unattached. The result is a stump with a rounded, fleshy end where the affected muscles are at a fixed length [16]. To mimic this condition of fixed muscle length in able-bodied subjects, the subjects were braced isometrically for each muscle group while it was in use. The subject was seated for all trials. A wrist brace was employed to hold the wrist in neutral position for each trial involving the wrist flexors and extensors. Bracing of the elbow was achieved by placing the shoulder in neutral position, placing the wrist in a supinated position, and strapping the subect's arm to the arm of the chair, preventing elbow flexion or extension at the humeroulnar and radioulnar joints. Bracing of the shoulder was achieved by placing the shoulder in neutral position and strapping the subject's arm to the arm of the chair. This

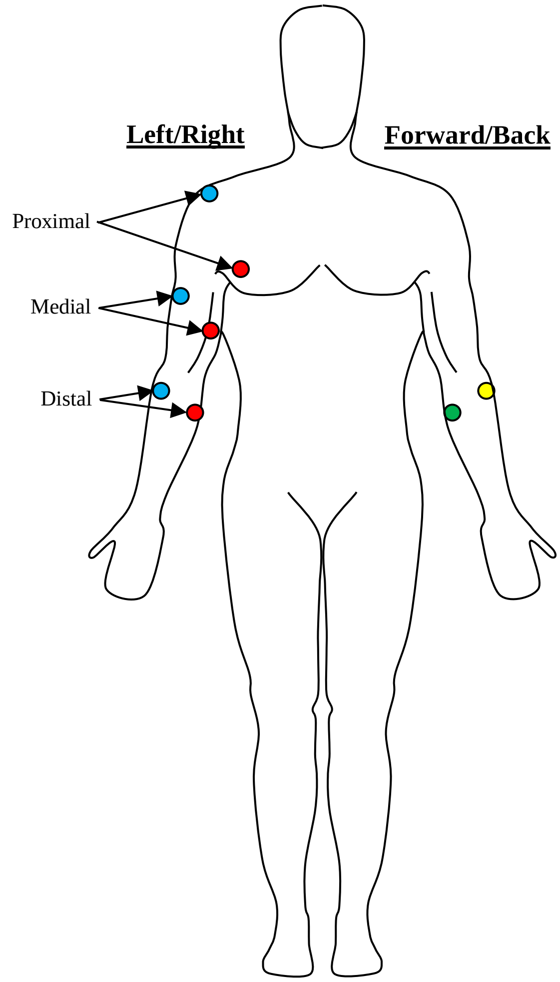

Fig. 1. Electrode placement locations used in the study and the corresponding actions they controlled.

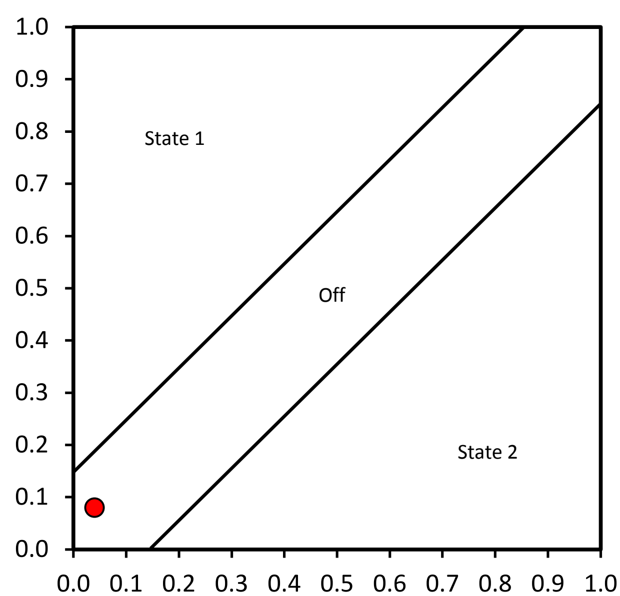

Fig 2. Relative signal display used in the signal training portion of the study. Each axis represents the EMG amplitude of one muscle normalized to MVC.

prevented internal and external rotation at the glenohumoral joint. Each muscle group underwent a calibration step when connecting the electrodes to the EMG instrument by asking the subject to produce maximum voluntary contractions (MVC) to be used for normalization of the EMG signals. The signals were converted to a percentage of this measured MVC rather than using their absolute amplitude, allowing for comparison between subjects, muscle groups, and electrode placements [11].

Although the training system used in this study is intended to replicate the functions of signal training and control training used with traditional training methods, the procedures in this study were structured as signal training, control training, and functional training tasks using the trainer in order to determine its effectiveness. Once the electrodes and braces were in place and the system had been calibrated, subjects performed an EMG signal training exercise.

A. Signal Training

Subjects were shown two plots similar to the one seen in Fig. 2, providing a live display of the amplitude of the EMG signals from the current muscle groups being measured in each arm. The X-axis of the plot was the EMG amplitude from the extensor or external rotator muscles in use as a percentage of MVC, and the Y-axis was the amplitude of the flexor or internal rotator muscles in use as a percentage of MVC, with the red dot moving in these two dimensions as subjects contracted their muscles. The result was that contraction of the flexor caused the red dot to move upward, contraction of the extensor caused the dot to move to the right, and co-contraction caused the dot to move diagonally. The diagonal lines on the display represented the cut-on thresholds for the group of muscles, or the minimum level of muscle activity needed to initiate the particular action. A lower cut-off threshold was used to terminate the actions, making it easier for subjects to use the actions requiring strong muscle contraction for longer durations without making it more difficult to use the neutral non-contraction actions, but this threshold was not shown on the display in order to avoid confusion.

To get the best possible control for the subject, the researcher first used the EMG signal display to help make adjustments to the individual EMG gains and thresholds to account for baseline muscle activity and electrode placement. This type of adjustment is quite common with this class of myoelectric devices, and continues to be used in many prostheses today [1]. The signal display was then used to provide subjects with signal training by observing the movement of the red dot on the screen in response to the movement of their muscles. The subjects were asked to contract their flexors, contract their extensors, co-contract both muscles, and relax in sequence, demonstrating for them the relationship between the contraction of their muscles and the movement of the dot on the screen. The signal training was complete when subjects were able to contract their muscles to hold the red dot in each area for at least 5 seconds on command, validating their control of the EMG signals.

B. Control Training

After the calibration and signal training phase was completed, subjects moved on to a control training phase. The car was placed in a 3’ by 3’ box in front of the subject, and they were asked to drive the car through a full 360° of rotation. This area was large enough to allow the car to turn, but small enough that the car could only make as much as a 45° rotation at a time, forcing subjects to practice making multiple turns both forward and backward in order to take the car through a full rotation. This training technique allowed subjects to adjust to the current control scheme for the car and have the opportunity to train to a baseline level of expertise before measurements began. The control training was complete when subjects successfully rotated the car 360° on the vertical axis, which typically required no more than one minute.

C. Functional Training

Following this control training activity, subjects moved on to the functional training and data acquisition phase by performing a driving task. Subjects were instructed to drive the car down a slalom course marked by cones on the inside of each turn and a marker on the outside of the turn, enclosing a distance two times the width of the car. The course was 5 feet wide and 40 feet long, with the cones for each turn spaced at 5 foot intervals down the length of the course. The course was designed with 8 turns of differing lateral spacing to provide variation in the turns required to complete the course, while still retaining the ability of the car to complete the course without needing to reverse or collide with anything if it was driven appropriately. The last half of the course was identical to the first half of the course except rotated 180°, providing an equal number and difficulty of turns both to the left and to the right. Subjects were instructed to attempt to finish as quickly as possible and to try to avoid hitting anything.

The remote controlled car used in this study was only equipped for digital control of its functions. As such, the car was limited to turning full left, full right, or straight, and it was limited to driving full speed forward, full speed reverse, or stopping depending on the signals it received from the controller. The car was fitted with a stepping voltage regulator to maintain a constant speed throughout the study regardless of the voltage of its battery, and was calibrated to travel at approximately 0.67 meters per second. As a baseline to compare the performance of subjects driving the car, the car was measured to be able to drive the length of the course in a straight line in 18.5 seconds.

The time each subject required to complete a trial was measured by a pair of light gates at the first and last cones of the course that were linked to a stopwatch, such that the stopwatch was started and stopped by driving the car past these cones. The time required to complete the course was recorded after each trial. While subjects were completing the trials, the experimenter observed the car and recorded the number of instances that the car collided with either a cone or a wall. After three trials had been completed for a muscle group, subjects were then presented with a 10 cm visual analog scale ranging from “very easy” to “very hard” and were asked to mark on the line how difficult they felt it was to complete the course using the current group of muscles for control. A linear measurement of this scale was used to quantify their subjective learning from the training. Additionally, the EMG signals from all four muscle groups during the trial were recorded and saved for later analysis. After all of these procedures had been completed for a muscle group, subjects moved on to the next muscle group in the sequence and began again at the calibration and signal training steps.

Because it can be difficult to provide a direct measurement of learning, the measured outcomes of these experiments are intended to be an indirect measurement of the subjects' skill in isolating the muscle movements necessary to activate the controls of the trainer. A steady decrease in the completion time and errors should indicate an increase in the subjects' skill in contracting the correct muscle at the appropriate time to initiate the desired action from the trainer. As the control scheme for a prosthesis would be about the same as the trainer, these skills should transfer over to being able to close the hand as desired at the appropriate time to pick up an object, as well as being able to prevent accidentally opening the hand and dropping the object.

III. INSTRUMENTATION

The design of the circuit driving the myoelectric trainer was based around an mBed™ embedded controller. The circuit was designed to accept four independent signals from a Noraxon MyoSystem™ 1200 EMG system through a twisted pair ribbon cable connector. The signal for each input channel passed through gain adjustment and offset adjustment circuits to condition the EMG signals from the subject to fit the detection range of the microcontroller. The microcontroller ran a program to process the raw EMG signals and drive the car, proceeding through a simple loop of collection, processing, and analysis of the resulting signals. The program ran at a constant rate of 1000 Hz, beginning with analog to digital sampling via polling of the incoming signals for later processing. The digital signals were then band-pass filtered between 20 and 200 Hz using a Butterworth filter in the software to remove any high or low frequency noise outside the frequency range of surface EMG. Following this, the signals were full-wave rectified to provide a signal with only positive values that could be used for control. The rectified signal was then run through a 100 millisecond rectangular smoothing window to change the sporadic impulses of the signal into a more continuous and smooth signal. This technique is commonly used in EMG analysis and is similar in function to a 6 Hz low-pass filter [11]. The final form of processing applied to the signals was normalization, where the current amplitude of the signal was converted to a percentage of the MVC amplitude found during calibration, allowing the system to compensate for both differences between users and variances in electrode placement.

After the signals were processed, they were compared to thresholds set during the calibration phase to determine which actions should be sent to the car. The difference between the amplitudes of the opposing muscle EMGs was calculated, and if the result was above one of the set thresholds then the corresponding action was sent to the car. A dual threshold system was employed to reduce fatigue in users while maintaining ease in selecting all three control states, with the

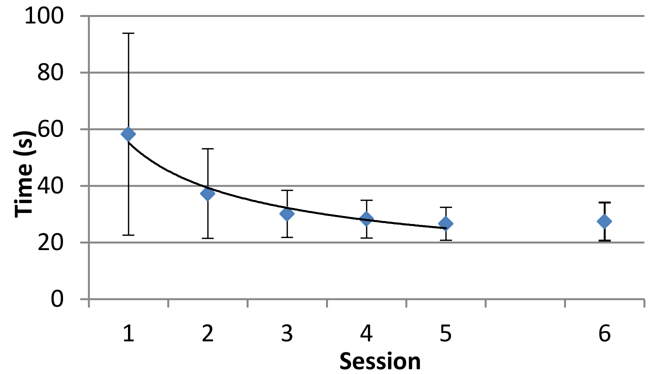

Fig. 3. Average time to complete a trial during each training session. Bars indicate SD.

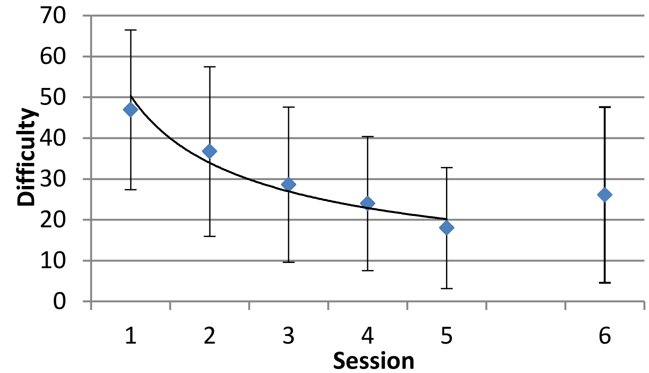

Fig. 4. Average subjective difficulty reported during each training session. Bars indicate SD.

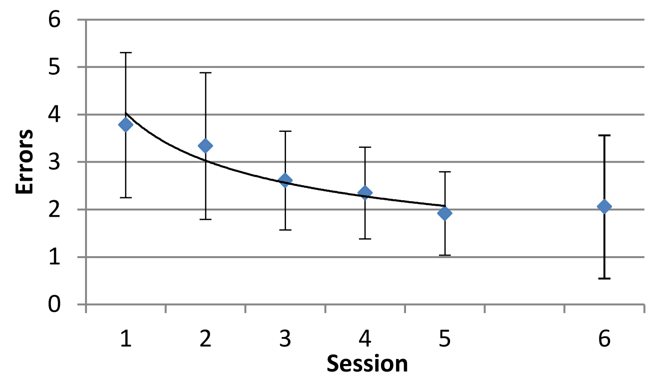

Fig. 5. Average errors occurring per trial during each training session. Bars indicate SD.

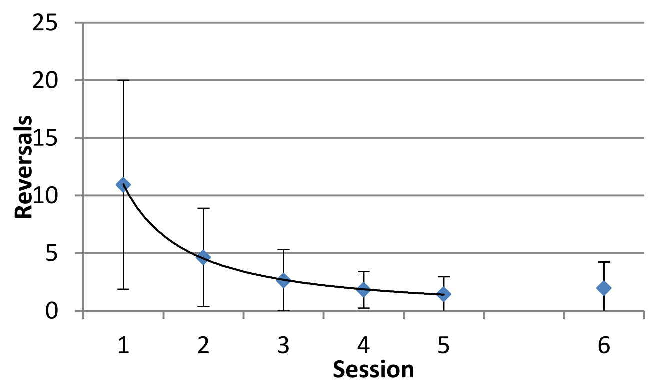

Fig. 6. Average reversals required to complete a trial during each training session. Bars indicate SD.

desired action being triggered when the signal rose above the upper threshold and remaining active until the signal dropped below the lower threshold for a set duration of time. These thresholds were typically set at 10% and 15% of MVC and were adjusted to accommodate for a muscle's baseline EMG. Finally, the data points from the processed EMG signals were written to a file for post-hoc analysis. At this point, the program paused until one millisecond had passed since the last measurement to maintain the constant 1000 Hz sampling rate, and the entire loop was repeated again.

IV. Results

The averaged results for time to complete the course, subjective difficulty, errors made, and reversals required were found to decrease significantly over time ($p<0.0005$), with the greatest changes occurring at the beginning of the training. Whereas the subjects required an average of 58.13 ± 35.7s to complete the course on the first day of training, their times had improved to 26.63 ± 5.84s by the fifth day of training, representing a 54% decrease in the completion time as well as a more consistent level of performance between subjects (Fig. 3). The subjects reported a similar decrease in their difficulty in driving the car over this time, with the reported difficulty decreasing 62% from 46.96 ± 22.25 to 18.00 ± 14.79 (Fig. 4). Aiding the improvement in completion times, the subjects' average number of errors dropped 49% from 3.78 ±1.53 to 1.92 ± 0.88 (Fig. 5), and the average number of reversals dropped 87% from 10.93 ± 9.06 to 1.44 ± 1.52 (Fig. 6). When the subjects were tested again after 90 days, a small decrease in performance was observed, but the difference was too small to be statistically significant, demonstrating retention of the skills learned over a longer time period.

The order in which the subjects were trained with the muscle groups did not produce a significant difference in performance. The use of the different muscle groups did not demonstrate a significant difference in performance either, but there was a small improvement in performance between the first and last muscle group used in the training.

No significant gender difference was observed in the time required to complete the course or the difficulty reported. However, there was a significant difference in the number of errors and reversals required to complete the course based on the subject's gender ($p=0.047$ and $p=0.048$, respectively), with the male subjects demonstrating better performance. In trying to identify a more concrete cause for this difference, a significant difference was noted in all four measures of performance based on whether or not a subject had experience with playing 3D video games ($p<.0005$). This difference can be seen in Fig. 7–10. Feng *et al.* found that there is a measurable difference between the genders with regard to spatial attention, but also found that playing certain types of video games could virtually eliminate the gender difference in spatial attention, as well as decrease the gender difference in mental rotation [17]. This was consistent with the performance of the subjects in this study, where mentally rotating the car to determine the best time to make the next turn would be important to achieving better results, and most of the female subjects demonstrated lower performance than the male

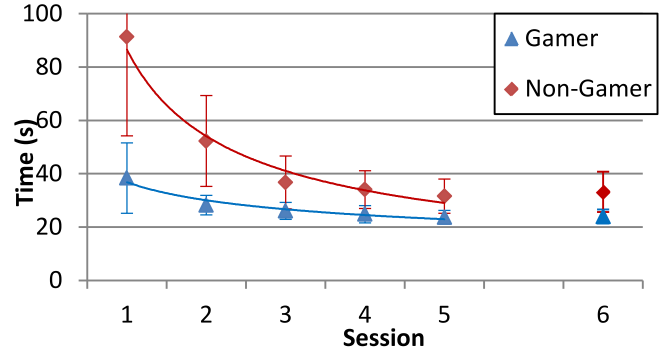

Fig. 7. Comparison of the average time to complete a trial during each training session for subjects who had experience with 3D games or no experience with 3D games. Bars indicate SD.

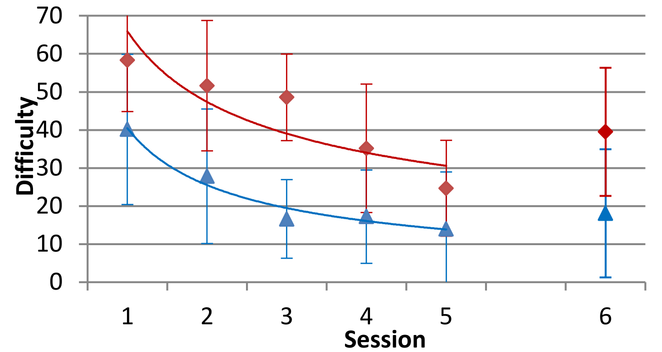

Fig. 8. Comparison of the average subjective difficulty reported during each training session for subjects who had experience with 3D games or no experience with 3D games. Bars indicate SD.

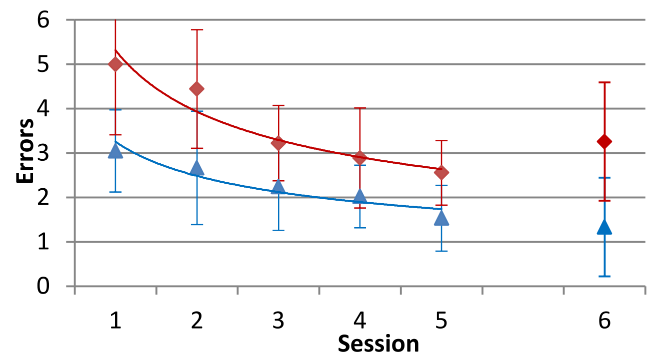

Fig. 9. Comparison of the average errors occurring per trial during each training session for subjects who had experience with 3D games or no experience with 3D games. Bars indicate SD.

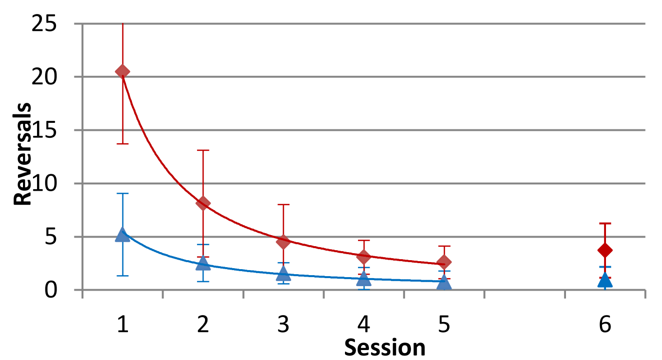

Fig. 10. Comparison of the average reversals required to complete a trial during each training session for subjects who had experience with 3D games or no experience with 3D games. Bars indicate SD.

subjects. The one female subject who did have experience with 3D video games demonstrated higher performance during the training than the other female subjects, and was even able to complete the course faster than all but one of the male subjects.

V. DISCUSSION

The primary objective of this study was to determine the efficacy of a novel type of training for the use of myoelectric prosthetic devices. This method allowed novice users to begin driving a remote control car through myoelectric control within a few minutes of the start of training. Their skill with controlling the car improved steadily over time, demonstrating better results between short weekly training sessions, as well as between sequential muscle groups within a single training session. The results indicated that by using this training method the subjects became more adept at using a myoelectric control scheme that is commonly used in commercial myoelectric prosthetic limbs.

These results were consistent with the results found in other studies, providing additional validation of this type of training device compared to other training devices that have been created. Other research has shown that subjects' time to complete tasks with the myoelectric training devices decreased over the course of the study asymptotically, with the greatest increase in performance occurring at the beginning of the study. The similar nature of the data collected in this study is taken as verification that this type of training can be used as an effective form of control training for myoelectric prosthetic devices [8] [15]. The asymptotic decrease in the subjects' time to complete the course was limited by the nature of the task, because the speed of the car and the length of the course defined the minimum time in which it was physically possible to complete the course. After only five short training sessions, the subjects were approaching the minimum of all of the measurements, showing that they were likewise approaching the limit of measurable myoelectric control skill that they could learn from this particular task. Further improvement would require creating another training task, moving to a more intricate myoelectric control scheme, or progressing the subjects on to the functional training step of prosthetic training.

There was a very large amount of variation in the subjects' performance with respect to time and reversals to complete the course. This variation appears to be due to the large difference between the initial skill levels of some of the subjects. The way that the variation decreased greatly over time demonstrates that this type of training was effective at training the subjects to a more uniform level of skill by the end of the study. The reported difficulty of the tasks also showed a fair amount of variation, but did not decrease as dramatically over the course of the training. This was likely due to the fact that this was a more subjective measure of the subjects' perception of the difficulty of the task, making this measurement more prone to error than the objective measurements.

The results of this study were also consistent with studies showing gender differences in the subjects' spatial thinking abilities [17]. It is thought that the better performance of the subjects with 3D game experience is due to an increased skill in mental rotation of the car similar to what was found in [17], which allowed them to better predict when to turn the car to avoid a collision. It was found that the use of 3D video games was able to effectively eliminate this gender difference, and even the subjects that did not use 3D video games were eventually able to train to use the car with a level of skill close to that of the subjects who did use the games. This stands as further evidence that this type of training was able to take subjects with a widely varying experience set and initial skill level, and then train them all to a uniformly high level of skill. Although it was not statistically significant for this sample size, it was also noted that the subjects who used 3D video games demonstrated better skill retention in the gap between the fifth and sixth training sessions than those who did not. When the mean and standard deviation of the performance measures were compared, the subjects who used 3D video games showed a smaller decrease in performance, or even an increase in performance, compared to the subjects that did not use 3D video games.

This research was intended to act as a pilot study for a new class of training devices for myoelectric prosthetic limbs. Because of this, it was thought that using non-amputee subjects in the experiment was not detrimental to demonstrating the validity of this type of training. The lack of amputee subjects is an acknowledged limitation of this study because the results with able-bodied subjects may not be generalizable to amputee subjects. A full validation of this type of devices would require the use of amputee subjects.

The design of the trainer was limited to one of the simplest forms of myoelectric control used in prosthetics due to the preliminary nature of this study. After the encouraging results obtained in this study, work has begun on the design and construction of a second generation training device that will be capable of proportional myoelectric control training. These improvements should result in a training device that is capable of utilizing the more complex myoelectric control schemes that are used in a variety of prosthetics. The design can also be improved by transitioning from using electrodes on two muscle groups on both arms (dual two-site three-state control) to only using one arm (two-site three-state control) to control the steering and some other method to control the propulsion. This would simplify the training to only require learning muscle isolation for a single arm.

Another shortcoming of the design of the current training device is that it is strictly a bench-top device. While this is sufficient for the purposes of experimentation, an end goal for these devices would be to miniaturize the electronics to the point that the training device could be worn suspended from the stump of the amputated limb. This would allow the user to remain mobile during the training as well as allowing the user to acclimatize to the sensation of wearing and using a myoelectric prosthetic as they moved around, making the training device more representative of the typical usage scenario of a prosthetic limb.

VI. CONCLUSION

This study verifies that this type of training device can be used to assist in learning myoelectric control schemes and training muscle isolation for myoelectric prosthetic hands. A validation experiment studied the performance of non-amputee subjects being trained with the device to assess the efficacy of this type of training. The subjects demonstrated a steady increase in all of the measured performance metrics throughout the course of the short training regimen. Although the initial performance of the subjects varied greatly, all of the subjects demonstrated an increasingly uniform level of skill with the tested control scheme as the training progressed. The experimental results presented indicate that a training device based on myoelectric control of a radio controlled car can provide an effective method for non-amputee subjects to train for control schemes used in commercial prosthetic hands.

REFERENCES

[1] A. Fougner, Ø. Stavdahl, P. J. Kyberd, Y. G. Losier and P. A. Parker, "Control of Upper Limb Prostheses: Terminology and Proportional Myoelectric Control - A Review," *IEEE Trans Neural Rehabil Eng,* vol. 20, no. 5, pp. 663-677, 2012.

[2] H. Bouwsema, C. K. Sluis and R. M. Bongers, "Learning to control opening and closing a myoelectric hand,," *Arch Phys Med Rehabil,* vol. 91, pp. 1442-1446, 2010.

[3] R. Ballance, B. Wilson and J. Harder, "Factors affecting myoelectric prosthetic use and wearing patterns in the juvenile unilateral below-elbow amputee," *Can J Occup Ther,* vol. 56, no. 3, pp. 132-137, 1989.

[4] N. Crone, "A comparison of myoelectric and stndard prostheses - A case study of a pre-school aged congenital amputee," *Can J Occup Ther,* vol. 53, no. 4, pp. 217-222, 1986.

[5] S. Millstein, H. Heger and G. Hunter, "Prosthetic use in adult and upper limb amputees: A comparison of body powered and electrically powered prostheses," *J Prosthet Orthot Int,* vol. 10, pp. 27-34, 1986.

[6] R. Stein and M. Walley, "Functional Comparison of Upper Extremity Amputees Using Myoelectric and Conventional Prostheses," *Arch Phys Med Rehabil,* vol. 64, pp. 243-248, June 1983.

[7] T. Takeuchi, T. Wada, M. Mukobaru and S. Doi, "A training system for myoelectric prosthetic hand in virtual environment," in *IEEE/ICME Internation Conference on Complex Medical Engineering,* Beijing, China, 2007.

[8] A. C. Dupont and E. L. Morin, "A myoelectric control evaluation and trainer system.," *IEEE Trans Rehabil Eng,* vol. 2, no. 2, pp. 100-107, 1994.

[9] M. R. Dawson, J. P. Carey and F. Fahimi, "Myoelectric training systems.," *Expert Rev Med Devic,* vol. 8, no. 5, pp. 581-589, 2011.

[10] L. Philipson and R. Sörbye, "Control accuracy and response time in multiple-state myoelectric control of upper-limb prostheses," *Med & Biol Eng & Comput,* vol. 25, pp. 289-293, 1987.

[11] P. Konrad, "The ABC of EMG: A practical introduction to kinesiological electromyography.," Noraxon, Inc., 2005.

[12] A. O. Perotto, Anatomical guide for the electromyographer: The limbs and trunk (4th ed.), Springfield, Illinois: Charles C Thomas Pub Ltd, 2005.

[13] K. E. Gordon and D. P. Ferris, "Proportional myoelectric control of a virtual object to investigate human efferent control.," *Exp Brain Res,* no. 159, pp. 478-486, 2004.

[14] J. S. Knutson, H. A. Hoyen, K. L. Kilgore and P. H. Peckham, "Simulated neuroprosthesis state activation and hand position control using myoelectric signals from wrist muscles.," *J Rehab Res Dev,* vol. 41, pp. 461-472, 2004.

[15] S. M. Radhakrishnan, S. N. Baker and A. Jackson, "Learning a novel myoelectric-controlled interface task," *J Neurophys,* vol. 100, pp. 2397-2408, 2008.

[16] R. Dederich, "Technique of myoplastic amputations," *Ann R Coll Surg Engl.,* vol. 40, no. 4, p. 222.226, 1967.

[17] J. Feng, I. Spence and J. Pratt, "Playing an action videogame reduces gender differences in spatial cognition.," *Psychol Sci,* vol. 18, pp. 850-855, 2007.

Ryan E. Clingman (M’09) received his B.S. degree in biomedical engineering from the University of Virginia, Charlottesville, VA, in 2010 and his M.S. degree in biomedical engineering from the Virginia Commonwealth University, Richmond, VA, in 2012. He is currently pursuing his PhD in Biomedical engineering from the Virginia Commonwealth University, Richmond, VA, and is expected to graduate in 2016.

Peter Pidcoe received his PhD in biomedical engineering from the University of Illinois at Chicago in 1993 and his Doctorate of Physical Therapy from the Virginia Commonwealth University in 2006. He is an Associate Professor and Assistant Chair in the Department of Physical Therapy at Virginia Commonwealth University in Richmond Virginia and an affiliate faculty in the Bioengineering Department at that same university. He has authored chapters in two books, 23 papers, and has patent pending on 3 inventions. His research interests include the design and development of rehabilitation tools for use with populations that have suffered neuroplastic changes.